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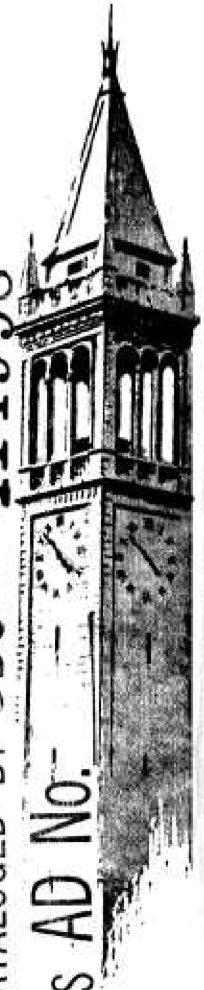

SUPPLEMENTARY CYLINDER DRAG DATA FOR TRANSITION FLOW CONDITIONS

by

G. J. Maslach

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I. INTRODUCTION

Previous measurements of drag forces acting on cylinders normal to a rarefied gas flow[1] have been concentrated in the transition and near free molecule flow range of Knudsen number where direct comparison with existing theories could be made. Following the completion of that work it appeared desirable to extend the data to near continuum flow conditions. In addition, the analysis of previous data by normalization techniques[2] indicated a need to repeat certain tests in an attempt to reduce experimental scatter. It is the purpose of this report to present all results obtained to date, including previous work and new measurements involving three additional models, with a complete listing of all data which may be of value to those contemplating future theoretical work in this field.

II. EXPERIMENTAL METHOD

A. Experimental Equipment

All tests were performed with the equipment previously described.[1] The three new models were solid steel rods; 0.0265 inch diameter, 0.0500 inch diameter and 0.1103 inch diameter. These supplemented the former models, 0.0003 inch, 0.0009 inch, 0.0015 inch, 0.0033 inch and 0.010 inch diameter. The same adjustable length cylindrical shields were used to fix the length of model exposed to the stream. The slotted caps terminating the shields were rebored to provide a close fit for each new model. Thus the ratio of shield diameter to model diameter varied with each model. No additional model temperatures were obtained with the new larger models.

B. Experimental Procedures

All procedures and flow control methods previously described were continued for the tests involving the three larger models. The length of exposed model varied from approximately three quarters of an inch to approximately two inches. Data obtained during a given run were immediately reduced to permit a plot of aerodynamic force versus model length. This control curve was thus available before changes were made in the experimental setup. The linearity of this plot and the extrapolation of the force data for a zero length model were constantly checked. As before, small positive force intercepts were noted for the theoretical zero length model for most of the runs.

III. DATA REDUCTION AND ERROR ANALYSIS

Standard methods of data reduction were employed to determine the free stream flow properties and the aerodynamic forces acting on the model. For the larger models the uncertainty in the quantity C_x was reduced due to the greater precision possible in the measurement of the model diameters. The larger forces, in the gram range, resulted in sizable spring extension and thus a reduction of this error source. The total of all error contributions in the determination of C_x for the three new models in all flow conditions varied from 1.5 to 2.0%.

It is interesting to note that the noticeable scatter in the original Mach 4 results using a 0.0033 inch nominal diameter model was traced to a change in model diameter in the course of the tests. The model, a butt welded thermocouple, was broken, repaired and remounted. In the refabrication the thermocouple joint in the center of the model length was

hand polished, resulting in a reduction in diameter of approximately 10%. New tests were run with this new cylinder and included in the final results for all models. These results are presented in Figures 1, 2 and 3 with a normalized presentation in Figure 4.

IV. RESULTS

The experimental results indicate a smooth transition from continuum drag coefficient values to predicted free molecular flow drag coefficients. Normalization of the measured drag values reveals a marked Mach number dependency. Future experimental programs are indicated, including extension to higher and lower Mach numbers, and a detailed pressure survey of the entire cylinder surface.

REFERENCES

1. G. J. Maslach & S. A. Schaaf, Phys. of Fluids 6, 3, 315-321 (1963).
2. F. S. Sherman, "Transition Flow - A Survey of Experimental Results and Methods for the Transition Regime of Rarefied Gas Dynamics," Univ. of Calif. Eng. Proj. Report HE-150-201, August 1962, and Rarefied Gas Dynamics (Proc. of 3rd Int'l Symposium on Rarefied Gas Dynamics, Paris, 1962), J. Laurmann, ed., Academic Press, New York (1963).

TABLE I. MACH SIX DRAG RESULTS

Mach Number M	Diameter (Inch) D	Static Pressure Microns Hg p_∞	Reynolds Number $Re_{D,\infty}$	Knudsen Number $K_{D,\infty}$	Drag Coefficient C_D	Normalized Drag Coefficient $\overline{C}_D$
5.96	0.050	119	540	0.0164	1.55	0.144
5.85	0.050	100	425	0.0205	1.55	0.144
6.08	0.026	106	270	0.0335	1.56	0.150
5.95	0.026	90	212	0.0417	1.58	0.169
5.89	0.010	130	110	0.0790	1.62	0.196
5.77	0.010	109	88	0.0975	1.67	0.229
6.01	0.0030	112	31.2	0.286	1.99	0.439
5.92	0.0030	93	24.2	0.364	2.07	0.493
5.94	0.0015	121	16.0	0.551	2.26	0.614
5.84	0.0015	100	12.5	0.694	2.32	0.654
6.08	0.0009	139	12.0	0.753	2.42	0.717
5.92	0.0009	93	7.26	1.211	2.55	0.803
6.00	0.0003	116	3.17	2.82	2.71	0.908
5.92	0.0003	93	2.45	3.60	2.75	0.932

TABLE II. MACH FOUR DRAG RESULTS

Mach Number M	Diameter (Inch) D	Static Pressure Microns Hg P_∞	Reynolds Number $Re_{D,\infty}$	Knudsen Number $K_{D,\infty}$	Drag Coefficient C_D	Normalized Drag Coefficient $\overline{C}_D$
4.06	0.110	112	298	0.0203	1.54	0.111
3.96	0.110	89	217	0.0272	1.55	0.117
4.06	0.050	111	138	0.0437	1.60	0.146
3.95	0.050	89	99	0.0595	1.64	0.169
4.06	0.026	112	70.2	0.0860	1.64	0.170
3.96	0.026	89	51.6	0.114	1.68	0.193
4.05	0.010	116	27.1	0.2219	1.76	0.26
3.97	0.010	91	20.0	0.2958	1.89	0.33
4.05	0.0030	112	7.84	0.7681	2.33	0.57
3.96	0.0030	88	5.73	1.027	2.46	0.65
4.06	0.0015	110	3.95	1.528	2.56	0.71
3.97	0.0015	86	2.86	2.064	2.70	0.79
4.05	0.0009	113	2.38	2.538	2.76	0.825
3.97	0.0009	87	2.33	3.457	2.86	0.88
4.06	0.0003	111	0.786	7.66	2.97	0.95
3.97	0.0003	87	0.575	10.27	2.98	0.96

TABLE III. MACH TWO DRAG RESULTS

Mach Number M	Diameter (Inch) D	Static Pressure Microns Hg P_∞	Reynolds Number $Re_{D,\infty}$	Knudsen Number $K_{D,\infty}$	Drag Coefficient C_D	Normalized Drag Coefficient $\overline{C}_D$
2.07	0.110	96	37.5	0.082	1.79	0.140
1.81	0.110	61	18.0	0.150	1.87	0.176
2.08	0.050	95	17.1	0.181	1.90	0.190
1.81	0.050	61	8.10	0.332	2.12	0.290
2.08	0.026	95	8.87	0.350	2.125	0.292
1.80	0.026	62	4.20	0.640	2.36	0.40
2.09	0.010	94	3.43	0.91	2.54	0.48
1.80	0.010	62	1.62	1.65	2.80	0.60
2.08	0.0033	94	1.06	2.92	3.16	0.76
1.77	0.0033	64	0.52	5.06	3.39	0.86
2.09	0.0015	94	0.511	6.09	3.46	0.90
1.78	0.0015	62	0.241	10.98	3.53	0.93
2.10	0.0009	93	0.305	10.23	3.55	0.94
1.80	0.0009	62	0.144	18.6	3.58	0.95
2.08	0.0003	95	0.101	30.6	3.66	0.99
1.85	0.0003	58	0.047	58.5	3.66	0.99

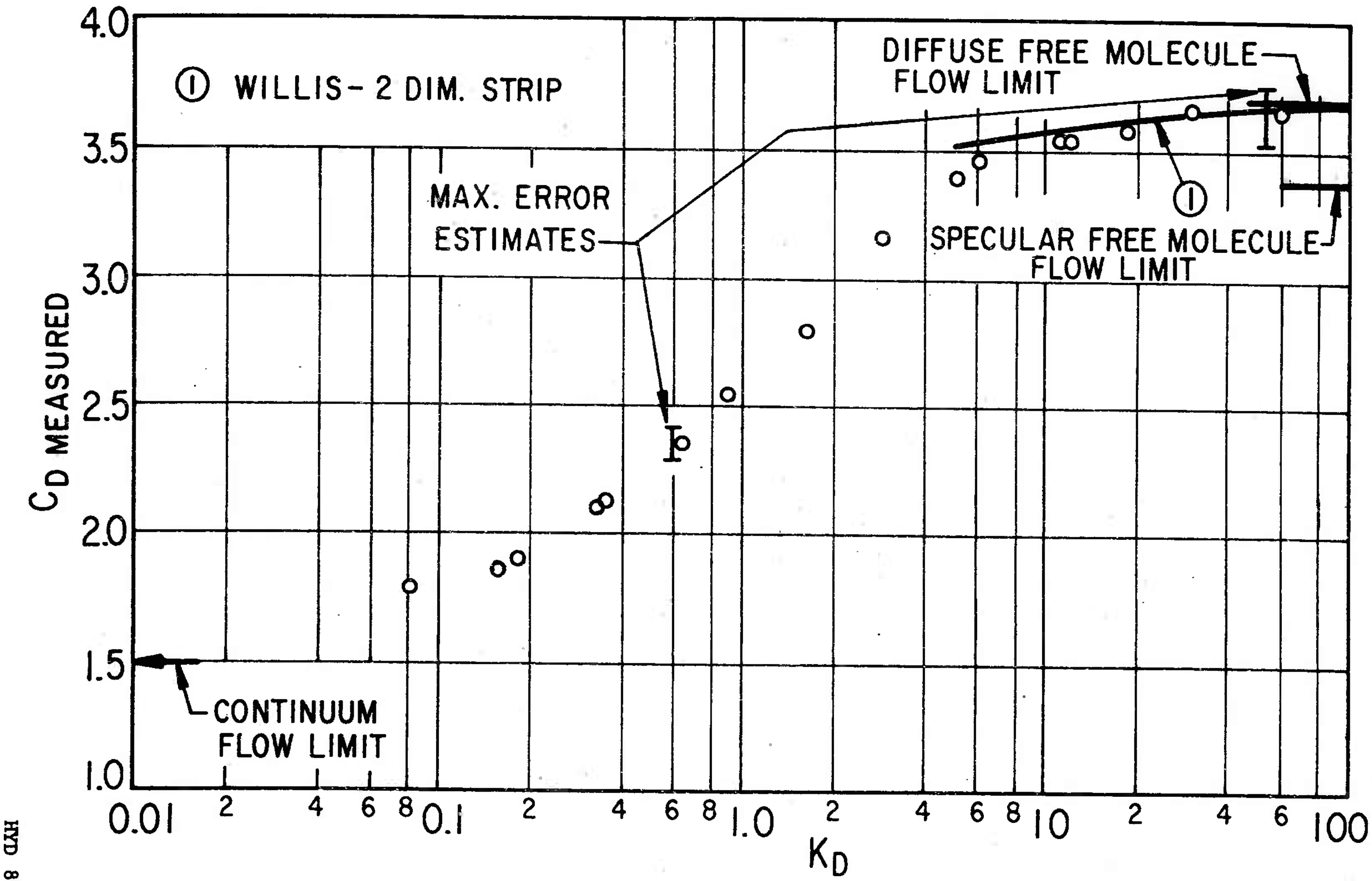

FIG. 1 CYLINDER DRAG AT M=1.96

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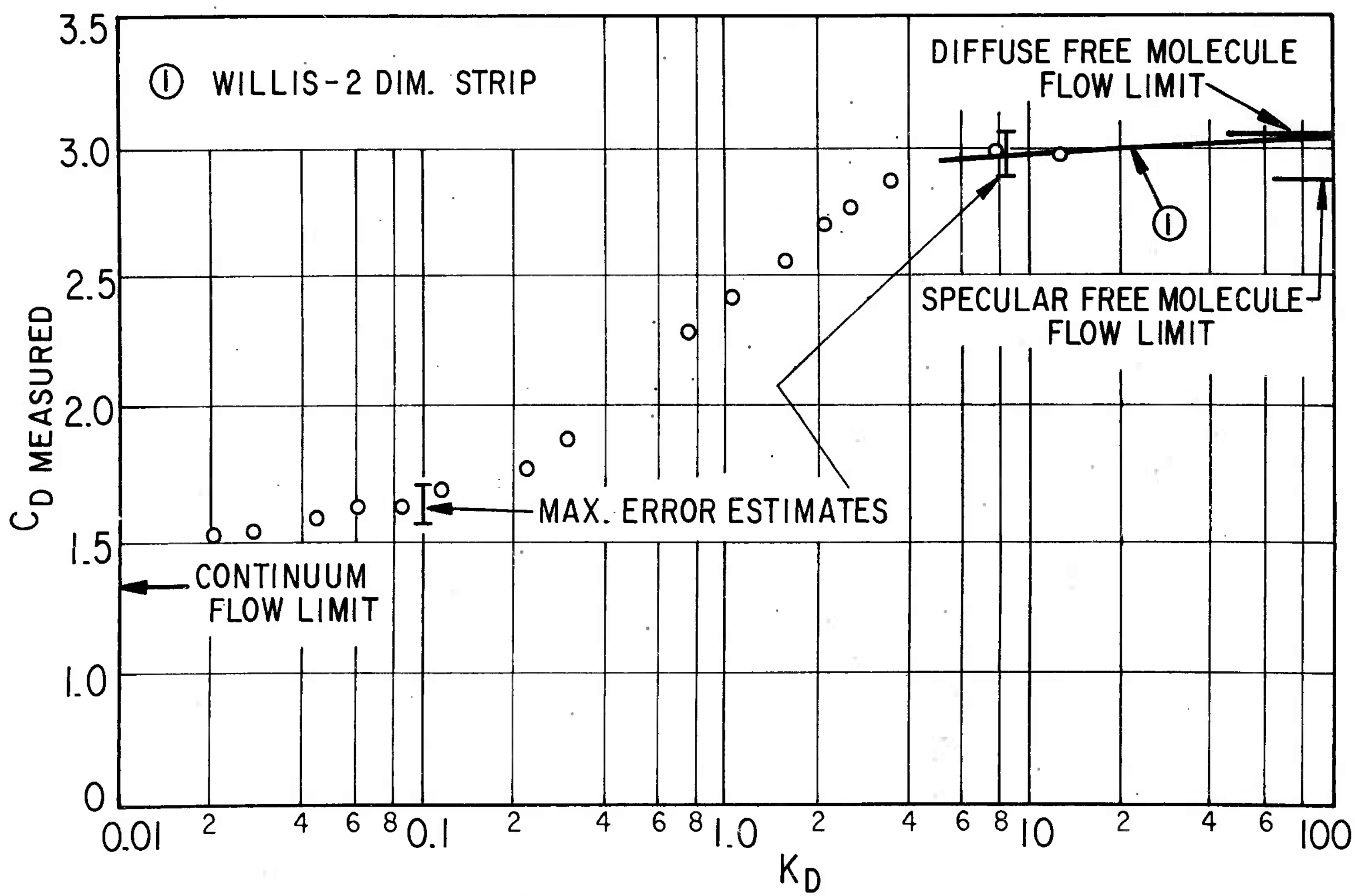

FIG. 2 CYLINDER DRAG AT M = 4.00

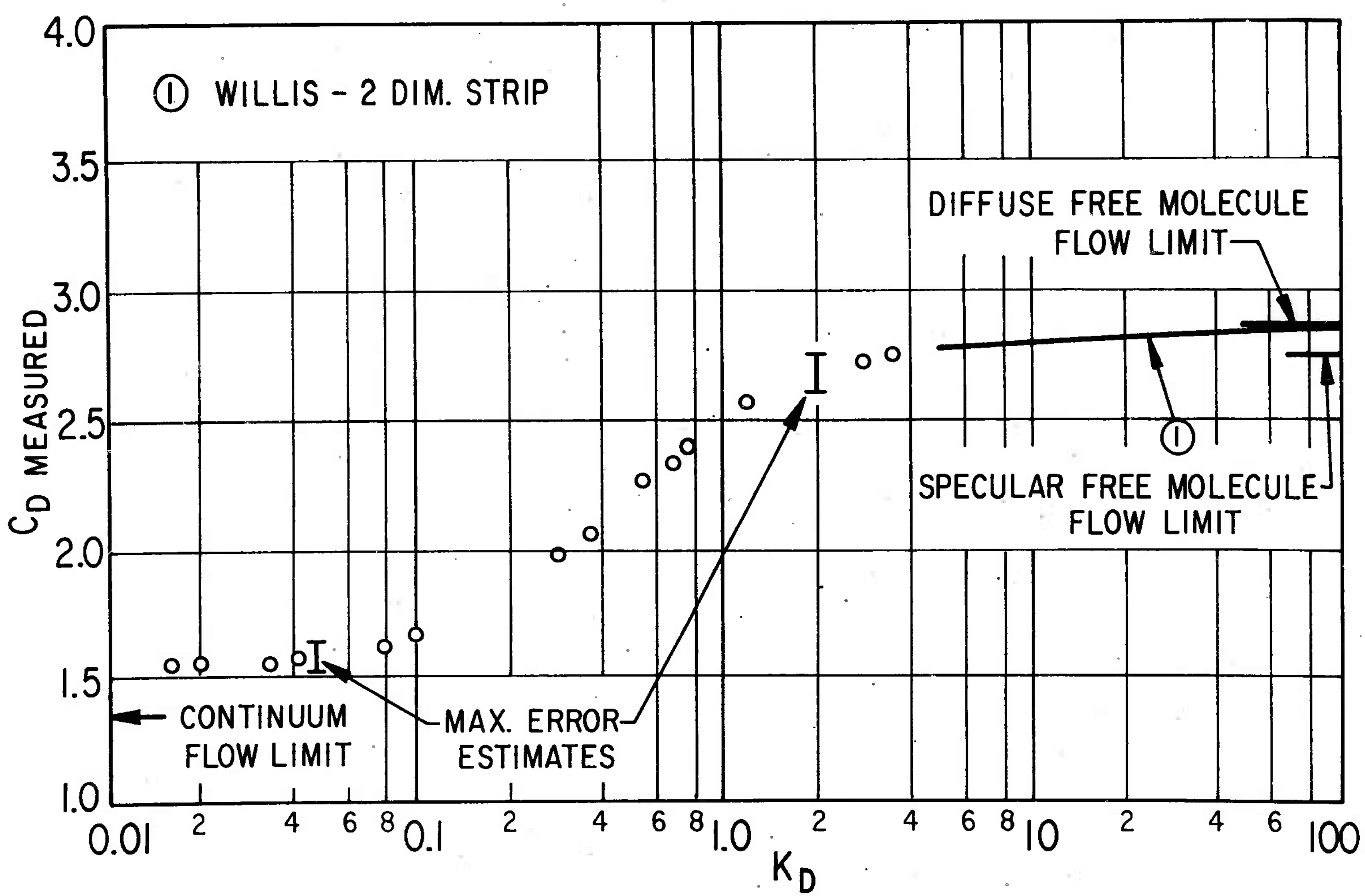

FIG. 3 CYLINDER DRAG AT M = 5.92

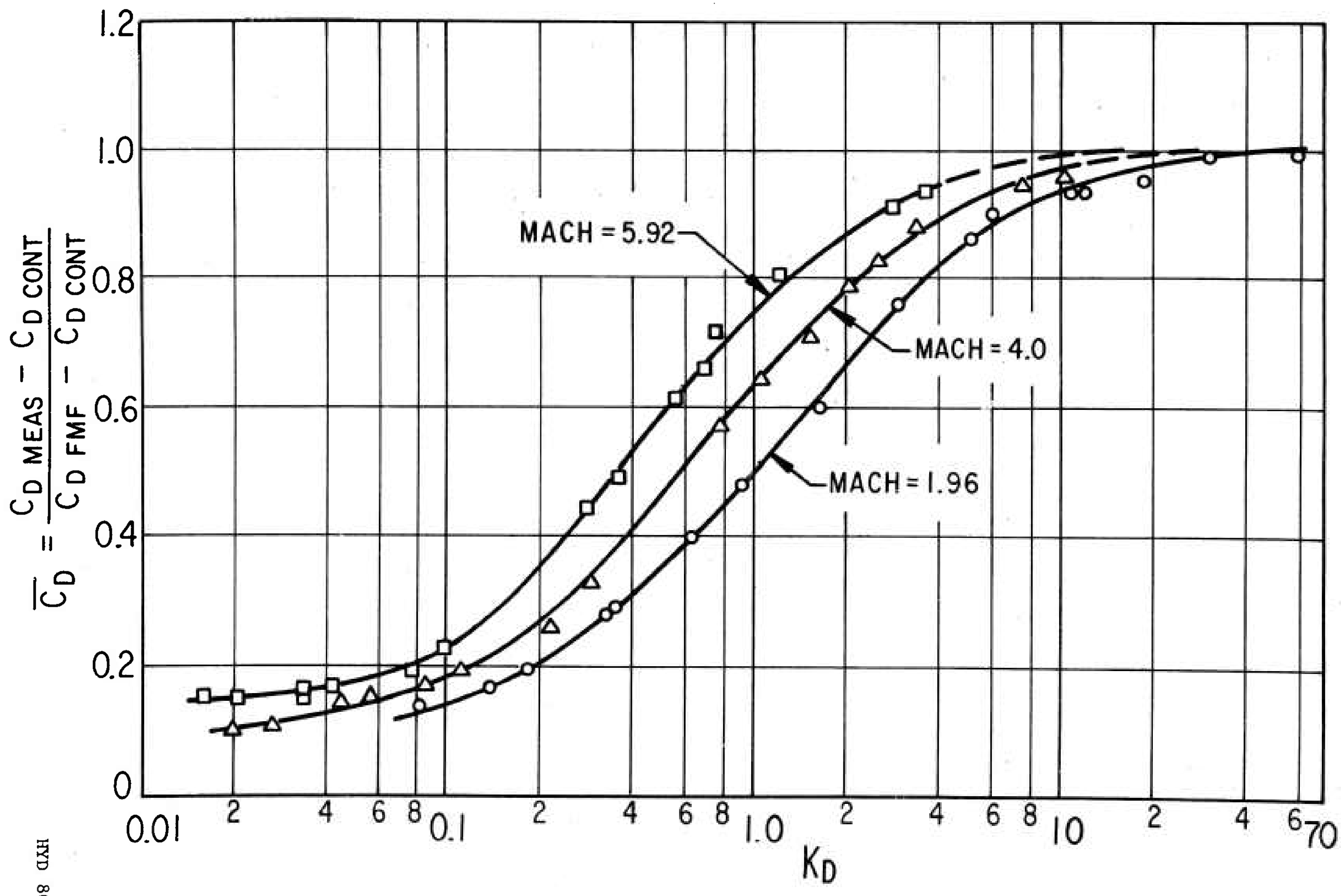

FIG. 4 NORMALIZED DRAG COEFFICIENTS vs KNUDSEN NUMBER

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